

SOHO/CELIAS/SEM 26-34 nm Absolute Irradiance Time Series from 1996 to 2014: a Revised Calibration and Comparison with Solar Indices

Seth Wieman, Leonid Didkovsky, USC Space Sciences Center, Los Angeles, CA, USA



**Abstract:** We present a new version of the SOHO/Solar EUV Monitor (SEM) 26-34 nm calibrated irradiance data obtained from measurements which span a time interval from the beginning of SEM operation in 1996 until now. It has recently been demonstrated that for the period of overlap between the SOHO and SDO missions, processing the SEM data using time-dependent reference spectra and updated SEM channel response functions results in SEM absolute irradiances that are in good agreement with those from the SDO/EVE. In the present work, we apply this approach to the entire SEM data set and additionally incorporate a revised degradation model that incorporates calibration under-flight measurements from 12 sounding rockets between 1996 and 2012. We discuss the formulation of the degradation model, verify it based on comparisons with concurrent measurements from SDO/EVE for recent dates, and present long-term comparisons of the new version of the SEM time series with the F10.7 and Mg-II core to wing ratio solar activity indices.

**I. Introduction:** The Solar EUV Monitor (SEM), part of the Charge Element and isotope Analysis System (CELIAS) onboard SOHO has measured absolute extreme ultraviolet (EUV) irradiance in the 26-34 nm band nearly continuously since January 1996. To maintain the long-term calibration of the SEM, a time- and wavelength- dependent degradation model has been established based on a series of sounding rocket under-flight measurements using a SEM clone instrument and a Neon Rare Gas Ionization Cell (RGIC) absolute detector. Recent improvements to the SEM calibration, which brought the SEM irradiance values into closer agreement with those from the SDO/EVE instrument for the period of overlap with the SDO mission, were reported in Wieman et al. (2014). These improvements included a more accurate SEM response function (measured at the NIST Synchrotron Ultraviolet Radiation Facility) and the use of time/activity-dependent solar reference spectra to determine irradiance values from the SEM broadband measurements in place of the single fixed reference spectrum (SOLERS22, Woods et al., 1998) used the previous Version 3.1 release of the SEM data. In the present work, we apply this data processing approach to the entire SEM data set dating back to 1996, using daily spectra from the Flare Irradiance Spectral Model (FISM, Chamberlain et al., 2007) as reference spectra. This work includes an updated SEM degradation model based on reprocessing of the previous sounding rocket data using the new approach, and the addition of several recent sounding rocket measurements not included in the previous version of the degradation model.

II. Updated SEM degradation model

The main source of SEM degradation is a reduction of signal with time attributed to the buildup and subsequent polymerization by UV radiation of a hydrocarbon contaminant on the thin film filters used in SEM for visible light rejection. In data processing SEM efficiency is reduced by a factor,  $f_{degrad}$ , equal to the wavelength dependent transmission of the contaminant layer, (modeled as carbon) given by:

$$f_{degrad}(\lambda) = e^{-\sigma_c \tau} \tag{1}$$

where  $\sigma_c$  is the wavelength dependent total absorption cross-section for carbon and  $\tau$  is the contaminant layer thickness that grows with time according to:

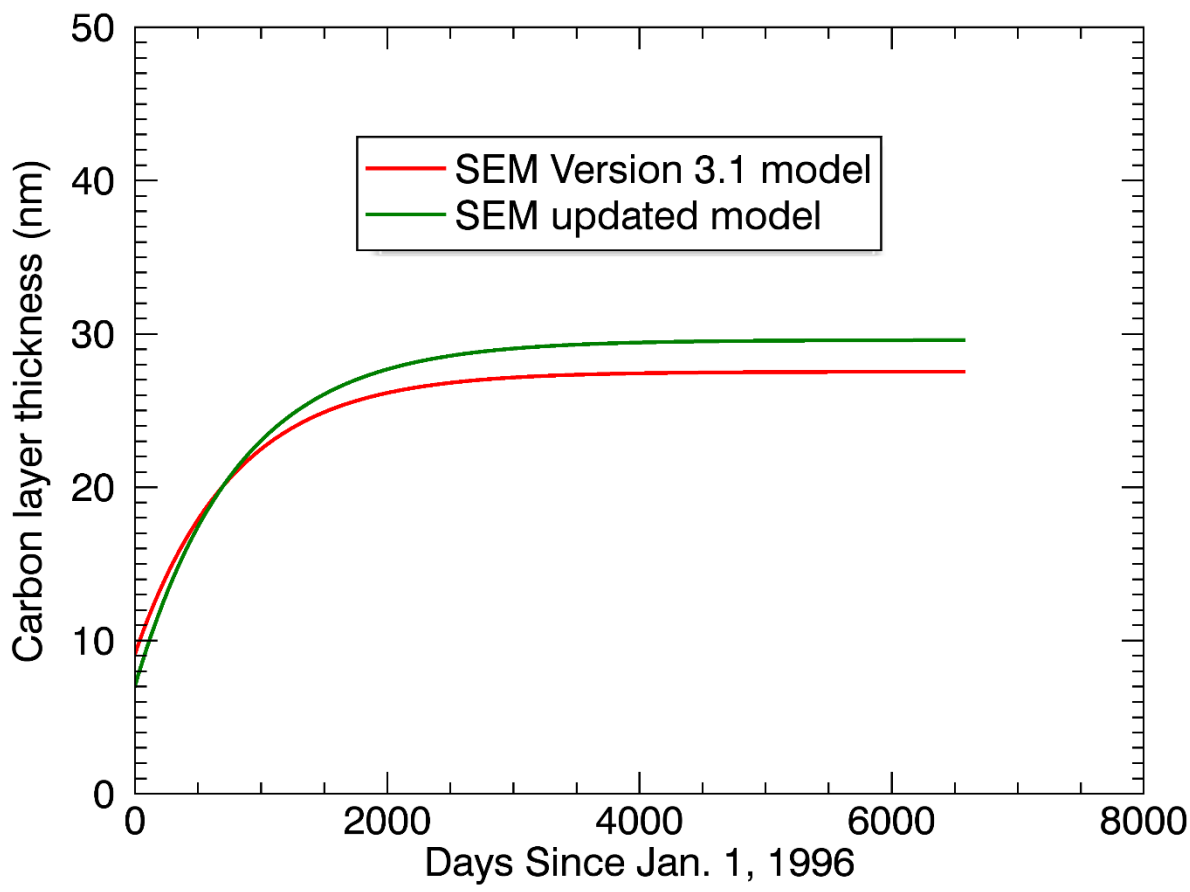
$$\tau(t) = a + b \cdot e^{-t/c} \tag{2}$$

where  $t$  is time from the beginning of the mission and  $a$ ,  $b$ , and  $c$  are parameters that are determined to minimize discrepancies between sounding rocket and corresponding on-orbit measurements shown in Table 1.

*Degradation due to hydrocarbon contamination is consistent with Henke model transmission curves and with the wavelength dependence of degradation observed on the EVE ESP instrument which includes a filter-wheel with redundant filters for monitoring such degradation.*

**Table 1:** Sounding rocket measurements used to determine the long-term degradation of the SOHO SEM. Parameters a, b, and c in equation (2) have been determined to minimize differences between the sounding rocket irradiance values (expressed in photon flux units in column 4) and concurrent irradiance measurements from the on-orbit SOHO SEM (column 5). The degradation model for SEM Version 3.1, prior to this work, was based on only the first 7 sounding rocket flights through Nov. 2006.

Date	Sounding Rocket Flight number	Calibration Instrument	Rocket meas. 26-34 nm flux (ph cm <sup>-2</sup> s <sup>-1</sup> )	SOHO SEM flux (ph cm <sup>-2</sup> s <sup>-1</sup> )	Ratio: SOHO SEM/ Rocket meas.
6/26/1996	36.147	SEM clone	1.13E+10	9.71E+09	0.86
		RGIC	9.71E+09		1.00
8/11/1997	36.164	SEM clone	1.12E+10	1.16E+10	1.04
		RGIC	1.17E+10		0.99
8/18/1999	36.181	SEM clone	1.76E+10	1.90E+10	1.08
		RGIC	1.90E+10		1.00
8/6/2002	36.202	SEM clone	2.25E+10	2.13E+10	0.95
		RGIC	2.21E+10		0.97
12/5/2003	36.211	SEM clone	1.59E+10	1.57E+10	0.99
		RGIC	1.50E+10		1.05
8/3/2005	36.227	SEM clone	1.43E+10	1.40E+10	0.98
		RGIC	1.37E+10		1.02
11/7/2006	36.236	SEM clone	1.11E+10	1.11E+10	1.01
		RGIC	1.04E+10		1.07
4/14/2008	36.240	EVE/ESP	8.59E+09	8.09E+09	0.94
5/3/2010	36.258	EVE/ESP	1.05E+10	1.05E+10	1.00
3/23/2011	36.275	EVE/ESP	1.25E+10	1.28E+10	1.02
6/23/2012	36.286	EVE/ESP	1.21E+10	1.16E+10	0.96
7/24/2012	36.263	SEM clone	1.32E+10		0.99
		RGIC	1.26E+10	1.30E+10	1.03



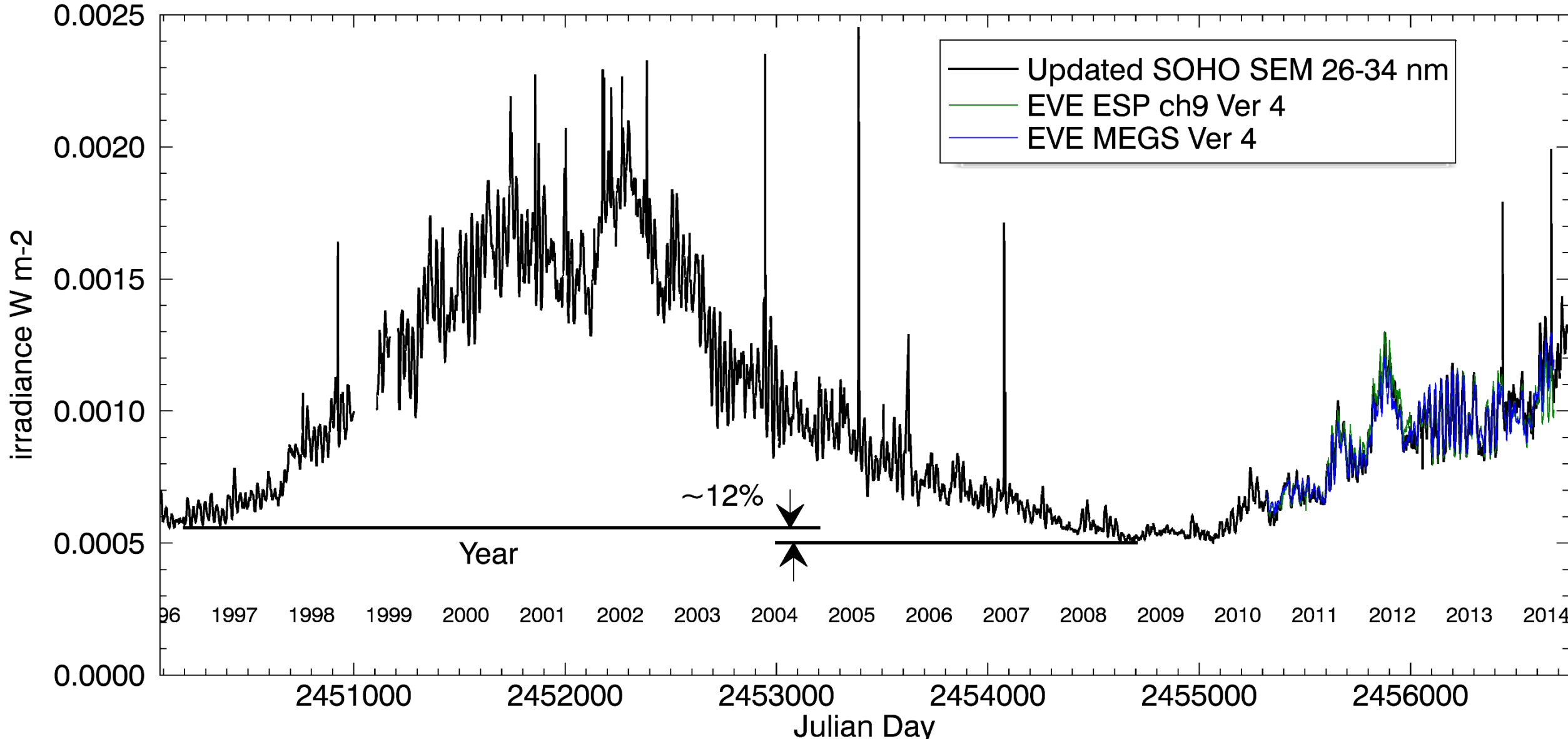
**Figure 1:** Carbon contaminant layer thickness as a function of time from equation (2) for the updated degradation model (green curve) and the Version 3.1 degradation model (red curve). The updated model indicates greater contaminant build up after ~750 days into the SOHO mission.

III. Reprocessed SEM time series 1996-2014

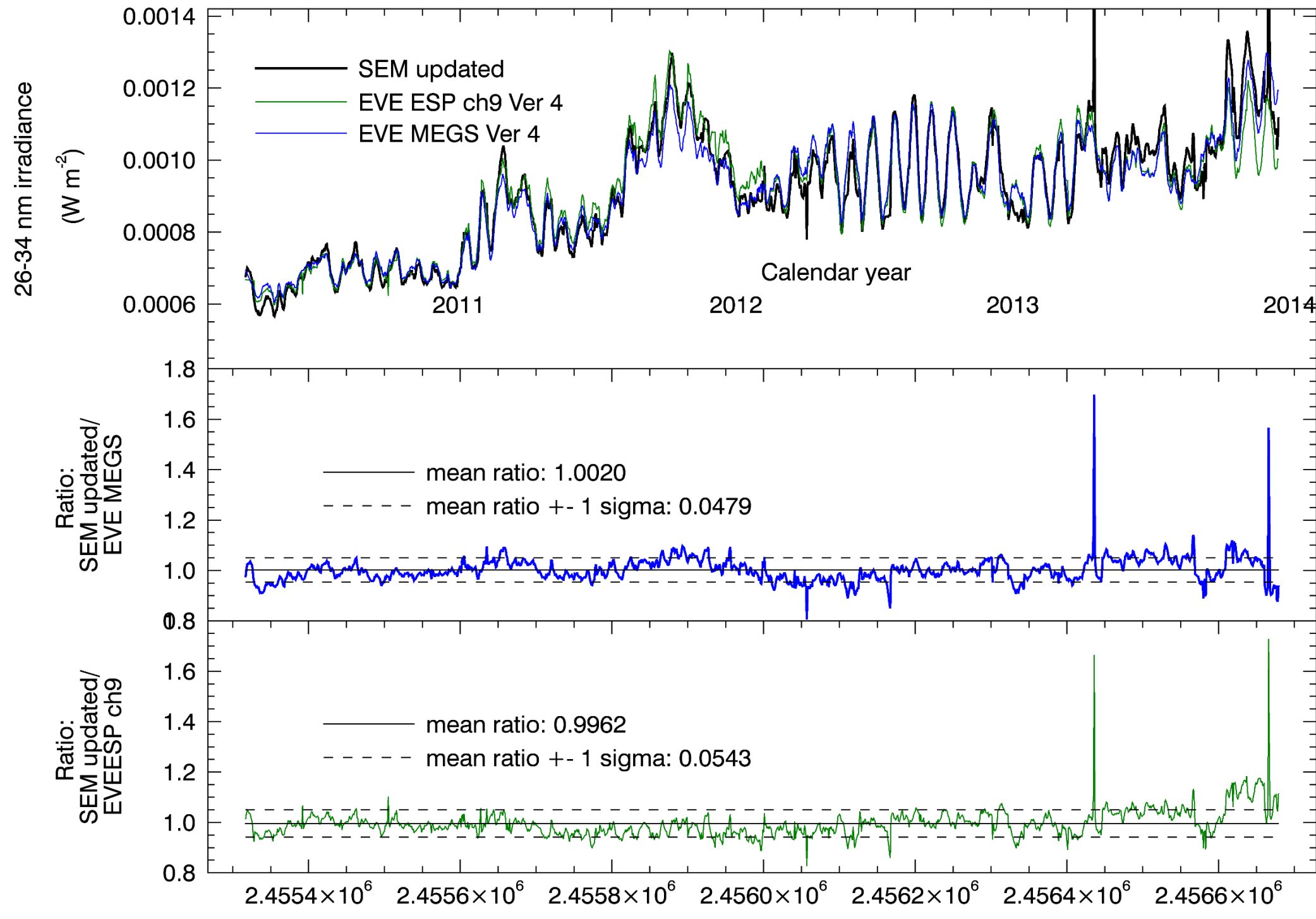
A revised calibration of the entire SEM 26-34 daily average data set has been completed with the following updates introduced since the most recent (Version 3.1) release:

- An updated SEM instrument response function (discussed in Wieman et al., 2014)
- Time/activity-dependent reference spectra from FISM (Chamberlain et al., 2007)
- An updated degradation model (section II of this work)

The updated SEM time series (Figure 2) results in a lower estimate of the difference in 26-34 nm EUV irradiance for the solar cycles (SC) 23/24 minimum compared to the SC 22/23 minimum. A change of about 12±4% is estimated based on the updated SEM calibration versus the 15±6% estimated based on the Version 3.1 release.

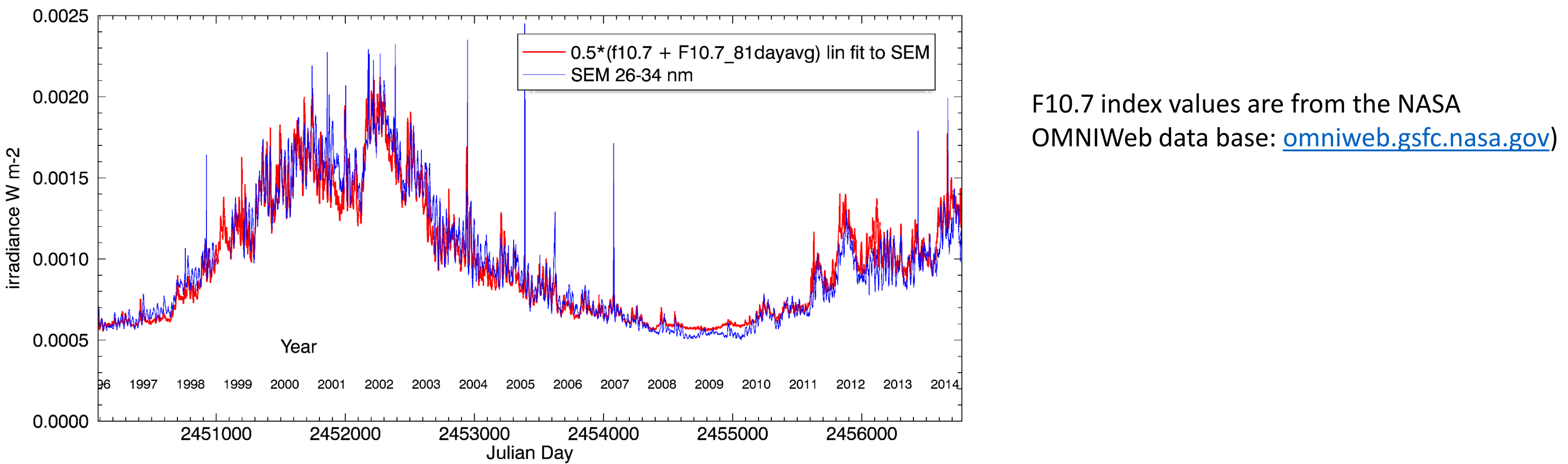


**Figure 2:** Updated SEM time series suggests 26-34 nm EUV irradiance was lower by ~12% during the SC 23/24 minimum compared to the SC 22/23 minimum. Measurements from SDO/EVE/ESP and from SDO/EVE/MEGS are shown for the period of overlap with SDO (and are compared in greater detail in Figure 3).

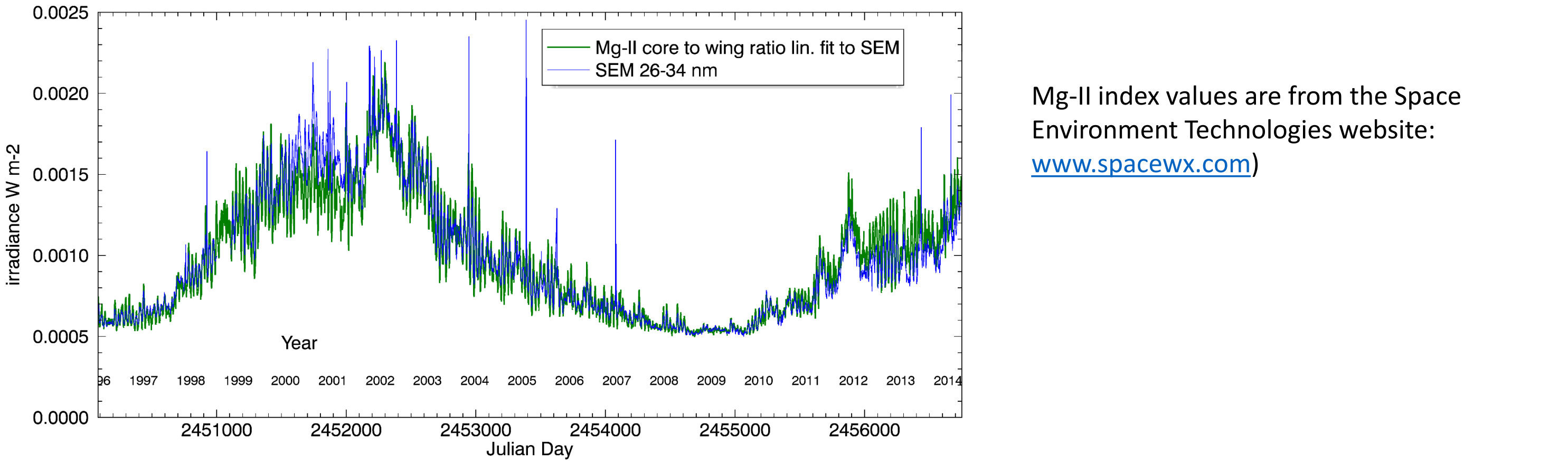


**Figure 3:** Top panel: A comparison of SOHO/SEM updated 26-34 nm irradiances to irradiances in the same band from the ESP and MEGS channels of the SDO/EVE instrument. Middle panel: daily ratio of SEM over MEGS (blue curve) plotted with dashed lines showing the mean ratio (1.002) and ratio STD (0.048). Middle panel: daily ratio of SEM over ESP (green curve) plotted with dashed lines showing the mean ratio (0.996) and ratio STD (0.054).

IV. Comparison with Solar Proxy Indices



**Figure 4:** Comparisons of SEM 26-34 nm time series with the F10.7 index (F10.7 daily and 81 day running mean values are averaged and linear fit to the SEM irradiances). The well-documented lower sensitivity of F10.7 to variations around solar minimum is evident as are differences during other intervals (e.g. around 1999 and between 2013 and 2014), however with about the same signals for the peaks between 2011 and 2012. These time intervals are isolated and not indicative of a steady long-term relative trend between time series.



**Figure 5:** Comparisons of SEM 26-34 nm time series with the daily Mg-II core to wing ratio (from Space Environment Technologies [www.spacewx.com](http://www.spacewx.com)) linear fit to the SEM data. The Mg-II index shows larger solar rotation variability and differences are evident at isolated intervals, but the good agreement over much of the time series (in the beginning and end in particular) does not suggest a steady long-term relative trend. The Mg-II index shows signal levels similar to SEM for the two latest solar minima and similar variability following the 2008 minimum, e.g. for the peaks between 2011 and 2012.

V. Conclusions

SOHO SEM daily average 26-34 nm irradiances spanning 18+ years have been reprocessed based on an updated instrument response function and degradation model and time/activity-dependent solar reference spectra. These irradiances are in good agreement (mean ratio of 1.00 and a ratio STD of ~0.05) with measurements from the ESP and MEGS channels of SDO/EVE for the period of overlap with SDO suggesting the SEM degradation has been appropriately corrected. Differences in comparisons with the F10.7 and Mg-II proxy indices are isolated without revealing a clear long-term trend, and are thus more consistent with differences related to source region and the solar phenomena each index is measuring rather than long-term instabilities in SEM.

Acknowledgments:

SOHO is a project of international cooperation between ESA and NASA  
This work was supported in part by University of Colorado award 153-5979

References:

- Chamberlin, P. C., T. N. Woods, and F. G. Eparvier (2008), *Space Weather*, **6**, S05001
- Wieman, S.R., Didkovsky, L.V., Judge, D.L. (2014), *Solar Phys*, **289**, 2907
- Woods, T.N., Ogawa, H., Tobiska, K., Farnik, F. (1998), In: Pap, J.M., Fröhlich, C., Ulrich, R.K. (eds.) *Solar Electromagnetic Radiation Study for Solar Cycle 22*, Kluwer, Dordrecht, 511.